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COMPRESSIVE STRENGTH OF CONCRETE MADE FROM NATURAL FINE AGGREGATE SOURCES IN MINNA, NIGERIA

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Abstract
This work presented an investigation of concrete developed from five fine aggregate sources in Minna, Niger state, Nigeria. Tests conducted on the fine aggregate samples included specific gravity, sieve analysis, bulk density and moisture content. The concrete mix design was done using absolute volume method at various mix proportion of 1:2:4, 1:2:3 and 1:1:2 and water-cement ratios of 0.4, 0.45, 0.5, 0.55 and 0.6. The compressive strengths of concrete were determined at 28-day curing age. Test results revealed that the specific gravities of the aggregate were between 2.60 to 2.70, compacted bulk densities also ranged from 1505.18 to 1701.15kg/m^3, loose bulk densities ranged from 1379.32 to 1478.17kg/m^3, and moisture content ranged from 0.93 to 2.47%. All the fine aggregate samples satisfied the overall and medium grading limits for natural fine aggregates. The coarse aggregate used fairly followed the grading limit for aggregate size of 20 to 5 mm. The compressive strength of the concrete obtained using the aggregate samples A, B, C, D, and E are all within the ranges of 18.97 to 34.98 N/mm^2. Statistical models were developed for the compressive strength of concrete as a function of water-cement ratio for various fine aggregate sources and mix proportions. The models were found to have good predictive the capabilities of the compressive strength of concrete for given water-cement ratio. The properties of fine aggregates and the resulting concrete characteristics showed that all the fine aggregate samples are suitable to be used for concrete production.

Key words: Characterisation, fine aggregates, compressive strength, concrete, models

1. Introduction

Various types of fine aggregates are being used in concrete production. The type of fine aggregate used changes the geometric properties of cement paste, and affect not only the shell formation during heat treatments, but also the properties of concrete. The quality of poured concrete must be determined to control the quality of production during the time required to remove the form work. The Compressive strength is directly related to other properties of concrete; if the compressive strength is high it guarantees that other properties such as flexural strength, modulus of elasticity and splitting tensile strength among others will also be high. Therefore it is an important criterion that must be followed while removing the form work from the concrete (Chi, *et al*., 2004).

Fine aggregates from different parent rocks exhibits different properties and this feature affects the properties of the resulting concrete produced. In most concrete work, fine aggregate properties such as bulk density, specific gravity and grading limits are not normally determined before they are used. The properties may not be ascertained. These uncertainties leads to several trials before optimum mixes are obtained (Neville, 1995). Abdullahi *et al.* (2008a) conducted trial mixes to develop concrete mix proportions for structural lightweight concrete using palm oil clinker as aggregate. Their work proposed feasible region for acceptable mix proportions. Also, due to the difficulty in concrete mix proportion, mix advisors have been proposed to aid mix design process (Abdullahi *et al.*, 2009a; Abdullahi *et al.*, 2009b; Abdullahi *et al.*, 2008b). The limiting zone in normal concrete is the mortar phase and the coarse aggregate/mortar interface (Abdullahi, 2012). The mortar phase is mainly controlled by the fine aggregates types while the coarse aggregate/mortar interface is controlled by both the nature of the fine aggregate and coarse aggregates. It is then obvious that fine aggregates plays important role in determining the reliability of a concrete (Topcu, 2004).

Generally, fine aggregates mostly used as fillers are found to exert significant characteristics on concretes as a consequence of both particle-packing and physico-chemical reactions in the interfacial zone (Camp, 2009). The use of fine aggregates increases concrete strength and this is mainly due to decrease in water-cement ratio. Curing of the concrete is normally carried out to ensure continuous hydration which would enhance strength and durability properties of the concrete. A standard of 28-day period is required under the water curing, although, normally the strength gaining continues beyond 28 days when there exist adequate moisture and favourable temperature conditions, for example, the American Concrete Institute (ACI) requires 7 days of moist curing for most structural concrete. However, the curing period for this work was at 28day.
Fine aggregates are available at various locations in Minna, Nigeria and its environs (Abdullahi, 2006). Efforts were earlier made to determine the properties of these fine aggregates (Abdullahi, 2006). His work revealed that the specific gravities of the aggregates in Minna, Nigeria were between 2.60 to 2.84, compacted bulk densities were between 1470 to 1867 kg/m^3, uncompacted (loose) bulk densities were between 940 to 1013 kg/m^3, and the aggregate grading varied from fine grading to medium grading and coarse grading. The gradations were found to be fairly close to the recommended values in (BS 882:1992) and were recommended for concrete work. However, fine aggregate materials vary considerably since they are from different rock fragments. However, the work of Abdullahi (2006) did not investigate any property of concrete developed from these aggregate sources. Investigation into the properties of concrete such as compressive strength will assist to provide better guidance to concrete community on the choice of fine aggregate sources for concrete production. Against this background, this work intends to investigate the properties of fine aggregates in Minna, Nigeria, obtain the compressive strength of concrete developed from such aggregates and develop statistical models for the prediction of compressive strength of concrete as a function of water-cement ratio.

2. Materials and Methods

This research involved the investigation of concrete made from various fine aggregate sources in Minna, Niger State Nigeria.
The fine aggregates used for this work were selected based on availability. Fine aggregate samples were collected at five selected locations within Minna township and were used for this research; the locations included: Tagwai Dam area designated as Sample A; Shata, Maikunkele area, Sample B; Paiko area, Sample C; RafinYashi, Bosso area, Sample D; and Gwada, Kuta Road area, Sample E.
The cement used in this work is the ordinary Portland cement (42.5N) with the capacity of attaining compressive strength of 42.5 N/mm^2 within 28 days period and having specific gravity of 3.15. This cement is the most widely used in Nigeria and hence its choice for this research.
The water used for mixing and curing of the concrete samples was potable water obtained from the tap at Civil Engineering Laboratory, Federal University of Technology Minna, Nigeria. BS 3148 specifies that any water that is suitable for drinking, such as tap water, is also suitable for concrete making. The tap water used in this work is therefore suitable for concrete production going by the requirement in BS 3148
Coarse aggregate used in this work is mainly gravel from crushed parent rock. Its maximum aggregate size was 20 mm. The smallest sieve size that allows all the coarse aggregate to pass through was 20mm sieve size. The physical properties of the aggregates used for the preparation of the test samples were determined in the Laboratory. The tests carried out on the aggregates include: sieve analysis in accordance to BS 812: part 1, bulk density in accordance to BS 812: part 2, specific gravity in accordance to BS 812: part 2, and moisture content in accordance to BS 812: part

109. The specific gravities were used to compute the mix composition required using absolute volume method.

2.1 Concrete Mix Design

For the purpose of this work, mix ratios of 1:2:4, 1:2:3 and 1:1:2 (cement: fine aggregates: coarse aggregates) and a water-cement ratio of 0.4, 0.45, 0.5, 0.55 and 0.6 were considered. Normal concrete was considered in this work. For a normal concrete, the water-cement ratios are normally above 0.4 and it was adopted in this work. Concretes with water-cement ratio below 0.4 are high performance concrete. Also the mix ratios used are commonly used in concrete production in Nigeria. This implies that for each of the mix ratios mentioned the four water-cement ratios were used to produce concrete of dimension 150mm x 150mm x150mm.

2.2 Calculation of mix proportions

The absolute volume method in which the sum of the solid volume of all the constituents of the concrete is assumed to be equal to one (Neville, 1995) was employed in the calculations of the mix proportions. This implies that

$$V_c + V_w + V_{FA} + V_{CA} + V_{air} = 1m^3 \qquad (1)$$

V_{air} = 2 % for maximum aggregate size of 19 mm (ACI 211.1-91).

Table 3.14 of ACI 211.1-91 permits the use of air content of 2% for maximum coarse aggregate size of 20 mm which was used in this work.

Thus,

$$\frac{W_c}{1000xSG_C} + \frac{W_w}{1000} + \frac{W_{FA}}{1000xSG_{FA}} + \frac{W_{CA}}{1000xSG_{CA}} + 0.02 = 1 \qquad (2)$$

V_C = Volume of cement, V_W = Volume of water, V_{FA} = Volume of fine aggregate, V_{CA} = Volume of coarse aggregate, V_{air} = volume of air, W_C = Weight of cement, W_W = Weight of water, W_{FA} = Weight of fine aggregate, W_{CA} = Weight of coarse aggregate, SG_C = Specific gravity of cement, SG_{FA} = Specific gravity of fine aggregate, SG_{CA} = Specific gravity of coarse aggregate.

In this work SG_C= 3.15, SG_{FA} = 2.64 (Samples A, B, C); 2.60 (Sample D), 2.66 (Sample E) and SG_{CA} = 2.70. Specific gravity is a dimensionless quantity and has no unit. Also W/C = Water-cement ratio, W= Water content (kg), C = Cement content (kg), FA = Fine aggregate content (kg), and CA = Coarse aggregate content (kg). Table 1 gives the mix composition of concrete for 1 m^3 of concrete measured in kg.

Table 1: Mix Composition of Concrete for 1m^3 (kg)

1:2:4	W/C	W	C	FA	CA
	0.40	131.85	329.61	659.23	1318.46
	0.45	145.87	324.16	648.33	1296.66
	0.50	159.44	318.89	637.78	1275.56
	0.55	172.58	313.78	627.57	1255.14
	0.60	185.3	308.84	617.68	123536
1:2:3	0.40	150.85	377.12	754.24	1131.36
	0.45	166.50	370.00	740.00	1110,00
	0.50	181.57	363.15	726.29	1089.44
	0.55	196.1	356.54	713.08	1069.62
	0.60	210.10	350.17	700.34	1050.51
1:1:2	0.40	212.43	531.08	531.08	1062.15
	0.45	232.68	517.07	517.07	1034.13
	0.50	251.89	503.78	503.78	1007.55
	0.55	270.13	491.15	491.15	982.30
	0.60	287.49	479.14	479.14	958.29

2.3 Compressive Strength Test

The compressive strength of the cube samples were obtained in accordance with the procedure given in BS 1881: Part 116. Moisture was drained off from the cube samples before their weight were taken and recorded. This was then followed by the crushing of the cubes at 28th day of curing under water in the Laboratory. The compressive testing machine used for compressive strength test was from the Concrete Laboratory of Civil Engineering Department, Federal University of Technology, Minna. The compressive strength test was conducted at loading rate within the range of 0.2 to 0.4 N/mm^2/s (BS 1881: Part 116).

2.3 Model Development

Statistical models were developed using the experimental data in Excel environment. Several models were tried using the "add trend line" menu. The models with the highest coefficient of determination were taken as the best model.

3. Results and Discussion

3.1 Specific gravity

Table 2 shows the values of the specific gravities of the aggregates. The average specific gravity obtained for the samples of fine aggregates ranged between 2.60 to 2.66, while that of coarse aggregate was 2.70 which fall within the range of 2.4 – 3.0 (Neville, 1995). The values of specific gravities obtained were fairly lower than those obtained by Abdullahi (2006). These may be due to difference in petrology of the fine aggregate materials (Neville, 1995).

3.2 Bulk density

Table 2 shows the values of the compacted and loose bulk densities of the fine and coarse aggregates. The values of compacted bulk densities of fine aggregates ranged from 1505.18 to 1701.15 kg/m^3, while that of loose bulk densities ranged from 1192.43 to 1495.41 kg/m^3. The values of the compacted bulk density are very close to those found by Abdullahi (2006), while the values of uncompacted bulk densities obtained are higher than those obtained by Abdullahi (2006). This implies that the aggregates considered here can be compacted into matrix with less pore spaces thereby producing concrete with more superior strength properties.

For coarse aggregates, the value of compacted bulk density and uncompacted bulk density were 1683.91 kg/m^3 and 1192.53 kg/m^3 respectively. Generally, the compacted bulk densities of the aggregates were higher than the loose bulk densities. This is because the loose aggregates might have contained more voids. When the aggregates were compacted, some of the voids were replaced by more aggregates, thereby increasing the weight which eventually increased the bulk density. Similarly, the ratio of loose to compacted bulk densities obtained fairly fall within the range of 0.61 – 0.87, hence this falls within the required specification of fine aggregate from natural source for concrete making (Neville, 995).

3.3 Moisture content

Table 2 shows the moisture content of the aggregates. The values of the moisture content of fine aggregates ranged from 0.93 to 2.47 % while that of coarse aggregates was 0.10 %. Neville (1995) asserted that fine aggregate can contain up to 10 % surface moisture content while coarse aggregate rarely contains more than 1 % of surface moisture. The values of the moisture content of the aggregates obtained were within the range provided by Neville (1995). Since these aggregates have surface moisture, it implies that the amount of water calculated from water-cement ratio has to be reduced in proportion of the amount of free moisture anticipated.

Table 2: Physical properties of the aggregates

Aggregate	Specific gravity	Loose bulk density (A) (kg/m^3)	Compacted bulk density (B) (kg/m^3)	A/B	Moisture content (%)
Sample A	2.64	1495.41	1532.19	0.98	2.47
Sample B	2.64	1450.00	1505.18	0.96	0.93
Sample C	2.64	1379.32	1692.24	0.82	1.15
Sample D	2.60	1478.17	1701.15	0.87	1.10
Sample E	2.66	1192.43	1675.00	0.71	1.16
Coarse aggregate	2.70	1192.53	1683.91	0.71	0.10

3.4 Sieve Analysis

Table 3 shows the gradation of both fine and coarse aggregates. The values of the percentage passing of both fine and coarse aggregates were compared with the specification in BS 882:1992. All the fine aggregate samples were found to have agreed with the overall and medium grading limits for natural fine aggregates. Also the coarse aggregate agreed reasonably well with the grading limit for aggregate size 20 – 5 mm. This implies that these aggregates can conveniently be used for concrete production with less mixture proportioning adjustment.

Table 3: Sieve analysis of the aggregates

	Cumulative % passing							
BS Sieve (mm)	Sample A	SampleB	Sample C	Sample D	Sample E	Coarse aggregate	Grading requirement: Fine aggregate (BS 882: 1992)	Grading requirement: Coarse aggregate (BS 882: 1992)
37.5								100
28.0						96		
20.0						79		90 – 100
14.0						38		40 – 80
10.0						13		30 – 60
5.0	100	100	96	93	99	3		0 – 10
3.35	100	100	93	91	98			
2.0	99	98	89	87	93		65 – 100	
1.18	93	91	84	80	57		45 – 100	
0.85	92	80	80	74	31			
0.6	77	49	72	63	11		25 – 80	
0.425	42	24	58	48	6			
0.3	17	9	21	28	2		5 – 48	
0.15	2	1	24	9	0			
0.075	0.3	0.4	0.9	4	0			
Pan	0.0	0.0	0.0	0.0	0.0	0.0		
Total								

3.5 Compressive strength

Figure 1 shows the relationship between compressive strength of concrete and water-cement ratio made using various fine aggregates at 1:2:4 mix proportion. The results of the test conducted show that concrete made with samples C and D produced the highest compressive strength of 24.13 and 24.16N/mm^2 respectively, followed by the compressive strength of sample B (23.77N/mm^2), E (23.33N/mm^2), and A (23.02N/mm^2) in that order. The higher compressive strength values were recorded at the water-cement ratio of 0.4 which is the minimum water- cement ratio. The relationships between compressive strength and water-cement ratio are quadratic, with coefficient of determinations ranging from 0.926 to 0.984. This shows that the models can explain the variability in the data of compressive strength to a minimum of 92.6 %. The variations in the compressive strength development are due to differences in the grading of the fine aggregate samples. This is in line with the findings of Neville (1995) and Abdullahi (2012). The regression models are all quadratic, except fine aggregate sample C which gave a linear regression model. However, all the models presented are similar in the sense that the exhibit a decreasing function as the water-cement ratio increases. This is in line with the works of Abdullahi (2012).

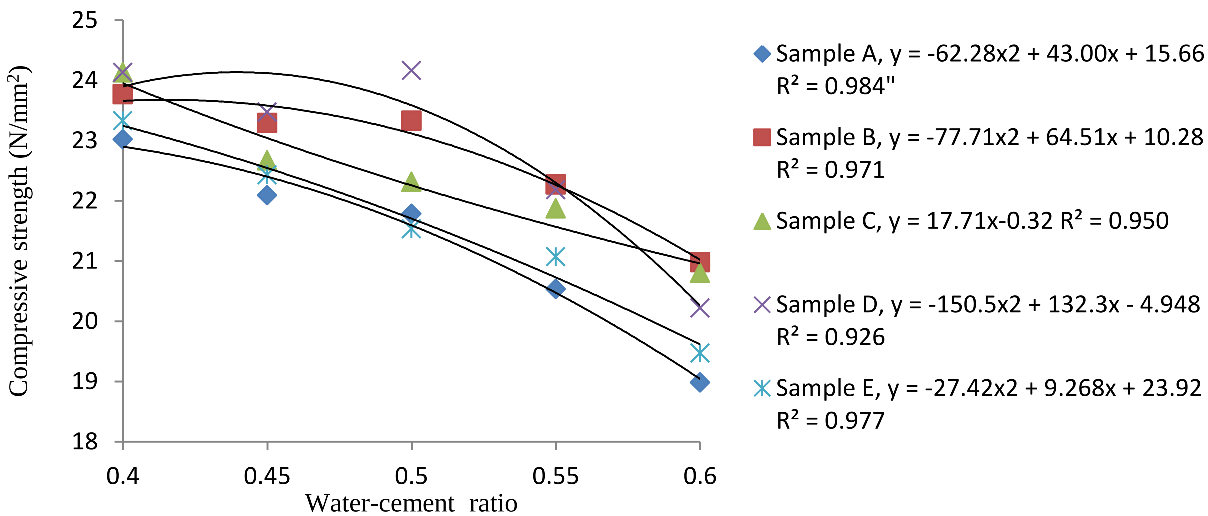

Figure 1: Relationship between compressive strengths 1:2:4 mix proportion and water-cement ratio

Figure 2 shows the relationship between the compressive strength of concrete made using various fine aggregates at 1:2:3 mix proportion. The results of the test conducted show that concrete made with sample A produced the highest compressive strength of 25.91N/mm^2, and it was followed by compressive strengths of sample C (24.98N/mm^2), E (24.53N/mm^2), B (24.49N/mm^2) and D (23.91N/mm^2) in that order. The highest compressive strength was obtained at water-cement ratio of 0.4 which is the minimum water-cement ratio used in this work.

Quadratic models were obtained for the relationships between compressive strength and water-cement ratios. These models have coefficient of determinations ranging from 0.975 to 0.991. This shows that the models have a good capability to explain the variability in the data of compressive strength to a minimum of 97.5 %.

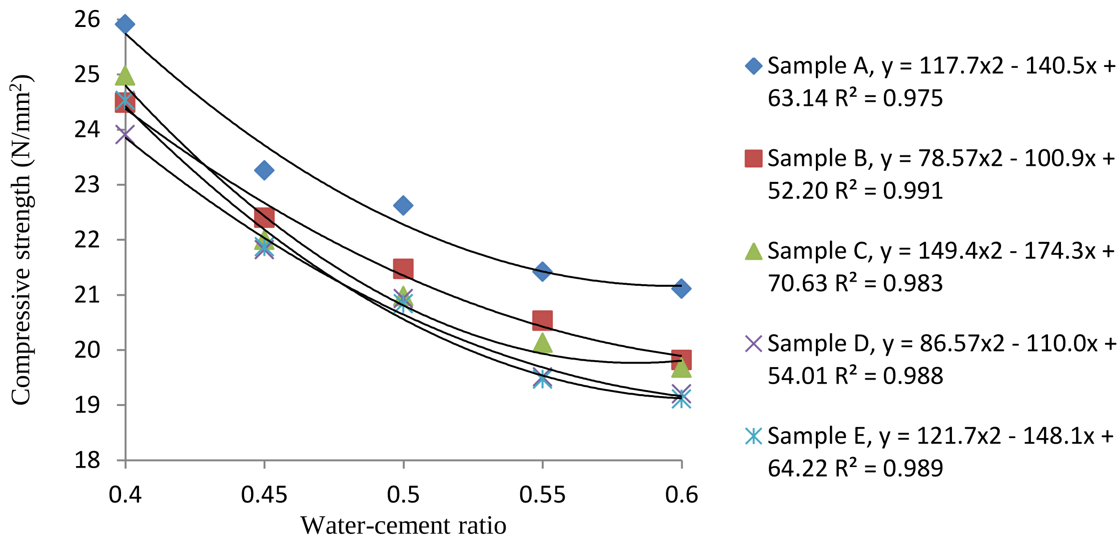

Figure 2: Compressive strength against water-cement ratio at 1:2:3

Figure 3 shows the relationship between the compressive strength of concrete and water-cement ratio made using various fine aggregates at 1:1:2 mix proportion. The results show that concrete made from sample A had the highest compressive strength (34.98N/mm^2), and it was followed by samples B and D with (31.51N/mm^2), sample C (30.51N/mm^2) and sample E (26.67N/mm^2) in that order. The highest compressive strengths were obtained at water-cement ratio of 0.4 which is the minimum water-cement ratio used in this work. The relationships between compressive strength and water-cement ratio are quadratic, except for fine aggregate sample E which gave a linear relationship with coefficient of determinations ranging from 0.891 to 0.90. This shows that the models can explain the variability in the data of compressive strength to a minimum of 89.1 %.

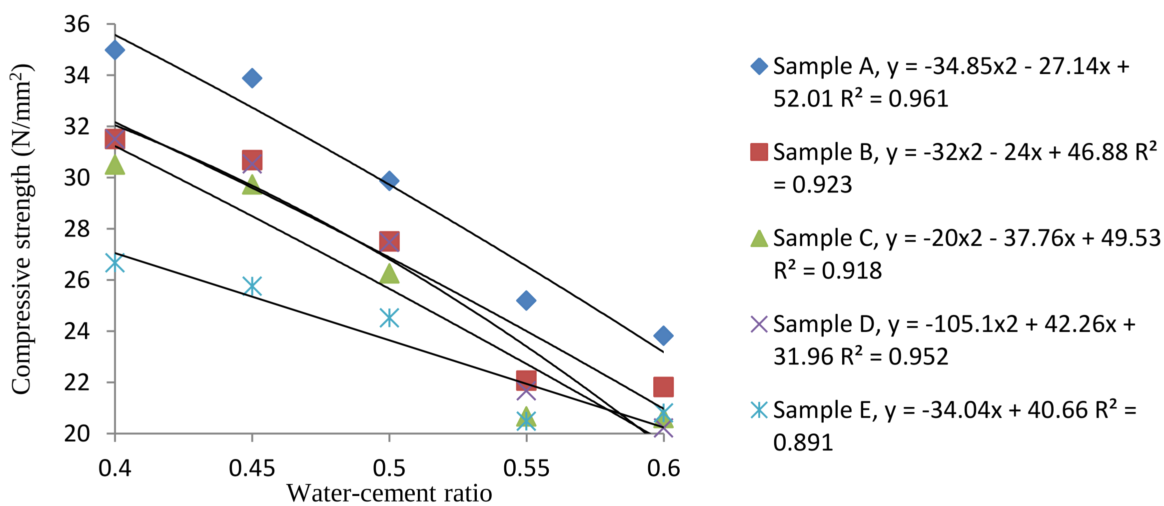

Figure 3: Relationship between compressive strengths 1:1:2 mix proportion and water-cement ratio

4. Conclusion

From the outcome of this study, the following conclusions were drawn:

1. The fine aggregates samples were characterised to be medium grading using the tabular data in BS 882:1990 and also satisfy the overall grading limits for natural fine aggregates. The physical

properties of the aggregates revealed that the aggregate from natural sources in Minna were suitable to be used for concrete work.

2. Lower mix ratios and lower water cement ratios were found to give higher compressive strength of concrete.

3. Statistical models have been developed for the prediction of compressive strength of concrete using fine aggregates from Minna and environs with values of coefficient of determination ranging from 0.891 to 0.991. This implies that these model is capable of explaining the variability in the concrete mixes by a minimum of 89%.

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